08/06/08
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RSS's Overhaul Interim Report

Current status (see *RSS_Overhaul_p.ppt*)

As of today we have performed all changes that were envisioned in the RSS overhaul planning stage. The changes that were performed are listed below (not in chronological or importance order)

Replacement of CCD(*)
Separation of two color glass filters
Introduction of purging system
New (epoxy-less) mounting of CCD
New Teflon o-rings
New shutter
Cleaning of optics
Optical alignment
Tuning CCD electronics for best nonlinearity

Unfortunately, we are unable to eliminate RSS instability that with almost 100% certainty is caused by contamination of windowless CCD with condensed chemicals that are still out-gassed most likely by the walls of the casting that constitutes the optical chamber. Newly developed dry air purging system did not eliminate the problem.

(*) New CCD had "thermoluminescence" effect in NIR and then it was destroyed. Additional tests were performed with old CCD

The original cause for the overhaul (see *RSS_DQ_issues.ppt*)

For over four years of its deployment RSS displayed two behaviors that deemed it to be an imperfect spectroradiometer. They were a short-term spectrally dependent instability and slight nonlinearity of its signal. Prior to the deployment the RSS, when tested in the ASRC lab, was almost perfectly linear and we think that we did not see the signs of the spectrally dependent instability. The nonlinearity steadily developed in the first three months after deployment and then stabilized. The spectrally dependent instability was observed during the first post-deployment radiometric calibration. A large part of the subsequent instability was – as we believe – due to common Spectralon diffuser ageing (soiling and solarization). However the instability that was most troublesome had a strong periodic spectral component. Initially, we hoped that the instability would eventually stabilize when the unidentified physical processes responsible for it would reach their plateau. Nevertheless, several years ago we have already proposed to perform the RSS overhaul. The effects of non-linearity and instability were countered with frequent (once every 2 weeks) calibrations that yielded both nonlinearity coefficient and new responsivity. Every-two-weeks responsivity correction (actually interpolation was used) was intended to maintain spectro-radiometric stability to be better than ±2%. Various tests and data analysis supported this supposition. However, recently while working on some RSS data we found a period in December of 2006 when this was not the case.

Final data massaging was obtained using Langley regression results on data that were already lamp-based responsivity corrected. The short-term instability did not go away as we hoped making frequent lamp-based calibrations necessary. So in the last year, when we have learned that the funds for the overhaul - proposed several years earlier - were granted, we decided to undertake the overhaul believing that we can make the RSS a better and much simpler instrument to maintain. Our theory was that the instability came from two possible sources: partial delamination of two cemented color glass filters and/or out-gassing related to contamination of the CCD surface. Both of these effects could cause etaloning-like behavior that would produce periodicity (in 1/wavelength space) in RSS responsivity.

Current results **(see *RSS_Overhaul_p.ppt*)**

When we opened the spectrometer we found the CCD to be heavily coated with viscous, but still liquid substance. On the other hand, we did not find signs of delamination between the two cemented filters. Also there was no major contamination of lenses and prisms. We concluded that the main culprit of RSS instability was and is CCD and changes it undergoes when its cold surface becomes a condensation center for the out-gassed chemicals. In the first stage of work we replaced the CCD with a new one. Assuming that out-gassing was complete, we sealed the cleaned optics with a new CCD. The new CCD displayed a NIR "thermoluminescence" effect, i.e., dark counts contained persistent (long relaxation time constant) residual signal after exposure to light. This effect - that we will call "thermoluminescence", but really do not know its nature, has been seen in the past, but it has never been acknowledged by the CCD manufacturer (e2v formerly Marconi and still before that EEV(*)). We are not 100% sure that the effect was not already present in the pristine CCD, i.e., we are not 100% sure that it was caused by the deposition of out-gassed substances on the CCD that were found after only a few days of testing once the optics were unsealed and opened. Still we were able to determine that the new CCD had significantly better linearity than the old CCD at similar CCD electronics settings. After this lesson we designed and built an optical chamber dry air purge system. In fact we anticipated this possibility and placed this task on the list of things to do in the planning stage of the overhaul. Also Jerry Berndt redesigned CCD mounting and used indium foil instead of silver epoxy to mount the CCD on the TE cooler. This was done in the belief that silver epoxy might be an additional source of out-gassing. Old CCD after being cleaned was installed. The old CCD did not displayed the "thermoluminescence" effect before nor after the cleaning. We are not certain that the old CCD did not sustain some permanent damage. But it appears that it works properly. The optical chamber was purged constantly during the last two weeks. However, we measured significant large (spectrally periodic) signal in the ratio of signals taken 14 days apart. Then after recycling power (heating up CCD for less than one hour) we observed similar instability in the signal. Twenty-four hours later the response had shifted by more than 2% non-uniformly with wavelength.

After opening the RSS we did not find a coating on CCD . However closer scrutiny of CCD surface suggests that over 5 year use it sustained some structural damage.

(*) Recent communication with e2v suggests that they might be aware of the effect causing what we call thermoluminescence. So it is no very likely that the effect was not caused by contamination but it existed in the CCD.

Outline of possible solutions

While we do not have all the answers nor certainty in success of possible actions to redeploy RSS, we must make substantial changes. These changes may go above and beyond the tasks that were scheduled for the overhaul. Before examining our options we briefly explain the nature of the RSS design and limitations it imposes on our solutions.

When the first RSS optics were conceived by Lee Harrison, I must presume that his utmost concern was to generate a design with the lowest possible stray light level. This made perfect sense for an optical system that would operate in the UV ozone Huggins bands region down to 295 nm. In fact the UV-RSS (295-380 nm) exists and has operated at Table Mt, Boulder, CO for over five years. This is an ASRC proptotype. Without doubt this instrument has the lowest stray light level among array-based spectroradiometers in the world (at least an order of magnitude better than grating spectrographs). The same could be said about our VIS-NIR RSS. This was accomplished by using refractive optics (prisms instead of gratings) and the fewest number of surfaces (singlets instead of achromats or even mirrors). For VIS-NIR range the RSS spectrograph added additional benefit of broad spectral range between (360-1100 nm) without using order sorting filters that are necessary when gratings are used. So the whole spectrum could be acquired with a single exposure instead of two exposures with and without the order-sorting filter.

In retrospect the costs of dealing with the secondary effects that were inherent in the design became very high. The refractive optics had to be thermally stabilized to within a fraction of a degree and air (or nitrogen) surrounding prisms should have constant density (sealed instrument) or constant (±5mb) pressure at constant temperature (purged unsealed optics) to maintain wavelength stability. These requirements would be much more relaxed if instead of prism a grating were used. The other cost, probably the highest, was due to the chromatically uncorrected optics that meant the image plane had to be tilted to achieve focus at all wavelengths, i.e., the CCD had to operate at oblique incidence. This large image tilt (see Figure 1) necessitated use of a windowless array (CCD). An array with window operating at large tilt generates multiple reflections between array (silicon) and window (fused silica) that increases stray light as wavelength increases. Finally, at some point in VIS or NIR the stray light level becomes unacceptably high.

Silicon diodes (NMOS or CCD) have temperature dependent quantum efficiency. For this reason they must be kept at constant temperature. The MFRSR silicon detectors are kept at 40-50°C. This high temperature is dictated by wide range of ambient temperatures in which the instrument must operate. Because of relatively small well depth (NMOS) and large dark electron levels (particularly CCD) the arrays used in the RSS must be kept at low temperature. In order to stabilize the optics, so they do not change with ambient conditions, the temperature of the optics must be kept high while the temperature of CCD must be kept low. This conflict leads to several problems: CCD becomes a condensation point (condensed water will destroy windowless CCD), and there is a large temperature gradient between TEC side of CCD and the air side of CCD. The temperature gradient with contamination may cause various chemical and physical effects that are probably unknown to anybody. YES, Inc. in cooperation with ASRC developed a design that was to be sealed with optics at 45°C and CCD at -5°C. In principle this approach could be successful if all sources of out-gassing were eliminated. As we now know this was not the case. In fact the casting used as the optics chamber by YES, Inc. became a major source of out-gassing. In the first RSS prototypes the temperature differential was smaller: optics at 25° and CCD at +7°C. This was accomplished with an additional air-conditioning (AC) unit that kept the optics box ambient temperature below 25°C within the external housing of the unit. The AC barely could manage during the hot summers of Oklahoma, and its first TE version did not last there for more than one year.

We do not think that complete elimination of out-gassing in general is possible. We may improve situation if we replaced the casting with stainless steel design but we would not solve it completely. For this reason we do not think that windowless array in a sealed design is a possible option. We could reduce effects of out-gassing by implementing aggressive purge, but again possibility of water leakage and subsequent damage to windowless CCD is not negligible during power shutdowns or dry air source failure. It is possible that front or back illuminated CCDs are more robust than the currently used open electrode (OE) CCD. The OE-CCD might be particularly susceptible to contaminant migration within them due to pinholes in the front surface. However, we do not know whether a windowless, front-illuminated CCD would be more stable in the presence of contamination.

For this reasons we believe that any solution should first target two chief problem makers: (a) windowless CCD and (b) temperature differential between CCD and optics. To use a vacuum-sealed CCD with window, we must have normal incidence on image plane. This can be accomplished with either achromatization of optics in the current design or by redesigning all optics and using grating instead of prism. The former is simpler and it preserves benefits of low stray light and the absence of the second order spectra. Achromatization can be accomplished by using achromatic doublets or by using mirrors. We could insert achromats in the current design with only small modification to the back plate and the hot finger of CCD. Using mirrors would amount to complete optical redesign and abandoning the present layout. Possibly it would be a better solution, but more costly. Achromats have their own problems due to the transmittance of the flint glass used in them. Most likely we would not be able to obtain signal below 360 nm. At this point we do not know which option to take. Learning more about achromats and doing extensive ray tracing of two options will be necessary.

To lower temperature differential between CCD and optics we can either use air-conditioning unit to operate optics at say 25° or place RSS in optical trailer with small opening on the roof. However it might be possible that CCD with window will not sustain damage due to out-gassing and deposited film on window will affect reponsivity only slightly because of small differnce between index of refraction of window on organic film. Also the reate of deposition will be much smaller because window will have substantially higher than CCD surface temperature. Furthermore aggressive purge may eliminate deposition.

What's on the table

I list possible options starting from the least expensive.

	Possible change	Positives	Negatives
A	Current purged system with windowless CCD (OE or BI type)	Stability better than before	Possible damage to CCD due to moisture leak.
B	CCD with window in achromatized system with doublets (with purging)	Best stability	Higher stray light and possibly lower resolution in UV-Blue
C	CCD with window in achromatized system with mirrors	Similar stray light as in (A) Best stability	Complete redesign of optics
D	New compact CCD-spectrograph module like in 4STAR (e.g. Zeiss + tech5)	Small and relatively inexpensive parts	Bad stray light (check with Connor Flynn), unknown stability, extra work to integrate into shadow-banding instrument (amounts to new RSS)
E	New grating spectrograph with commercial CCD camera	Most stable, constant resolution in whole spectral range,	Worse stray light than (A) or even (B), filter sorting needed – very expensive amounting to completely new RSS (a lot of work on new electronics)

Currently we are proposing option B. At minimum we estimate that additional costs of $10k for Jerry Berndt's consulting and $5k for parts (more if BI CCD would be used) would have to be added. Unfortunately we do not have 100% certainty that this (the least radical change) would work. But we think that 90% confidence level in success should be assumed. We think that this could be accomplished in one moth of work. Currently both Jerry Berndt and I have open October that we could exclusively devote to RSS. At the moment I am trying to get more information on CCD options (BI vs. OE) and achromats to get their parameters for ray-tracing.

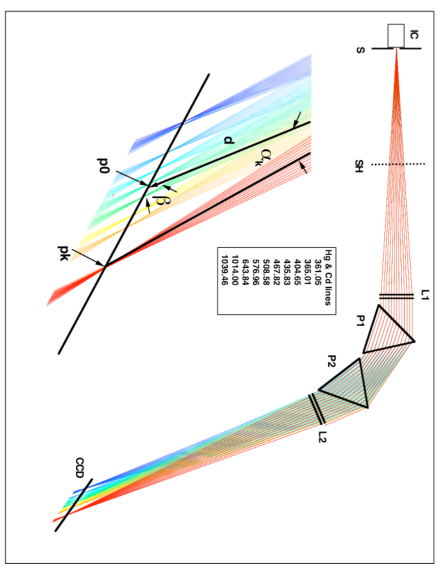

Figure 1. Current RSS Optical Configuration